

Lesson 5

Fabric Filter Design Review

Goal

To familiarize you with the factors to be considered when reviewing baghouse design plans for air pollution control programs.

Objectives

At the end of this lesson, you will be able to do the following:

1. List and explain at least six factors important in good baghouse design
2. Estimate the cloth area needed for a given gas process flow rate
3. Calculate the number of bags required in a baghouse for a given process flow rate
4. Calculate the gross air-to-cloth ratio, the net air-to-cloth ratio, and the net,net air-to-cloth ratio for a baghouse design

Introduction

The design of an industrial baghouse involves consideration of many factors including space restriction, cleaning method, fabric construction, fiber, air-to-cloth ratio; and many construction details such as inlet location, hopper design, and dust discharge devices. Air pollution control agency personnel who review baghouse design plans should consider these factors during the review process.

A given process might often dictate a specified type of baghouse for particulate emission control. The manufacturer's previous experience with a particular industry is sometimes the key factor. For example, a pulse-jet baghouse with its higher filter rates would take up less space and would be easier to maintain than a shaker or reverse-air baghouse. But if the baghouse was to be used in a high temperature application (500°F or 260°C), a reverse-air cleaning baghouse with woven fiberglass bags might be chosen. This would prevent the need of exhaust gas cooling for the use of Nomex felt bags (on the pulse-jet unit), which are more expensive than fiberglass bags. All design factors must be weighed carefully in choosing the most appropriate baghouse design.

Review of Design Criteria

The first step in reviewing design criteria is determining the flow rate of the gas being filtered by the baghouse, which is measured in cubic meters (cubic feet) per minute. The gas volume

to be treated is set by the process exhaust, but the filtration velocity or air-to-cloth ratio is determined by the baghouse vendor's design. The air-to-cloth ratio that is finally chosen depends on specific design features including fabric type, fibers used for the fabric, bag cleaning mechanism, and the total number of compartments, to mention a few. Figure 5-1 depicts a number of these design features. A thorough review of baghouse design plans should consider the following factors.

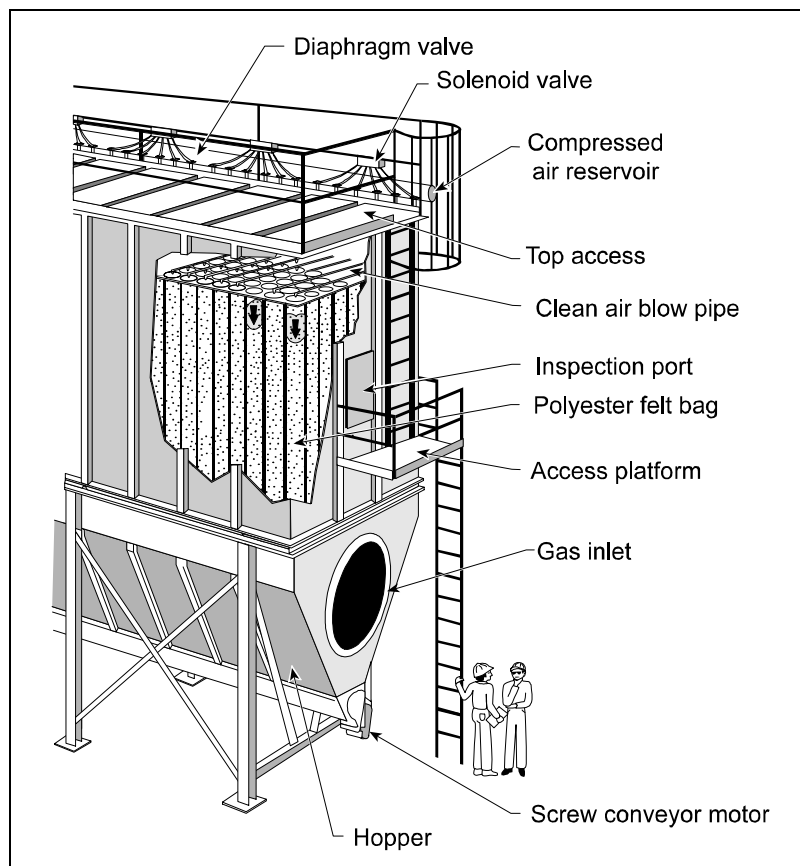


Figure 5-1. Design considerations for a pulse-jet baghouse

Physical and chemical properties of the dust are extremely important for selecting the fabric that will be used. These include size, type, shape, and density of dust; average and maximum concentrations; chemical and physical properties such as abrasiveness, explosiveness, electrostatic charge, and agglomerating tendencies. For example, abrasive dusts will deteriorate fabrics such as cotton or glass very quickly. If the dust has an electrostatic charge, the fabric choice must be compatible to provide maximum particle collection yet still be able to be cleaned without damaging the bags.

Predicting the gas flow rate is essential for good baghouse design. The average and maximum flow rate, temperature, moisture content, chemical properties such as dew point, corrosiveness, and combustibility should be identified prior to the final design. If the baghouse is going to be installed on an existing source, a stack test could be performed by the industrial facility to determine the process gas stream properties. If the baghouse is being installed on a new source, data from a similar plant or operation may be used, but the baghouse should be designed conservatively (large amount of bags, additional compartments, etc.). Sometimes,

heavy dust concentrations are handled by using a baghouse in conjunction with a cyclone pre-cleaner, instead of building a larger baghouse. Once the gas stream properties are known, the designers will be able to determine if the baghouse will require extras such as shell insulation, special bag treatments, or corrosion-proof coatings on structural components.

Fabric construction design features are then chosen. The design engineers must determine the following: woven or felt filters, filter thickness, fiber size, fiber density, filter treatments such as napping, resin and heat setting, and special coatings. Once dust and gas stream properties have been determined, filter choice and special treatment of the filter can be properly made. For example, if the process exhaust from a coal-fired boiler is 400°F (204°C), with a fairly high sulfur oxide concentration, the best choice might be to go with woven glass bags that are coated with silicon graphite or other lubricating material such as Teflon.

Along with choosing the filter type the designer must select the appropriate **fiber type**. Fibers typically used include cotton, nylon, fiberglass, Teflon, Nomex, Ryton, etc. The design should include a fiber choice dictated by any gas stream properties that would limit the life of the bag. (See Lesson 4 for typical fabrics and fibers used for bags.) For more information about fabric construction, see McKenna and Turner (1989).

Proper air-to-cloth (A/C) ratio is the key parameter for proper design. As stated previously, reverse-air fabric filters have the lowest A/C ratios, then shakers, and pulse-jet baghouses have the highest. For more information about air-to-cloth ratios, see McKenna and Turner (1989).

Once the bag material is selected, the **bag cleaning methods** must be properly matched with the chosen bags. The cost of the bag, filter construction, and the normal operating pressure drop across the baghouse help dictate which cleaning method is most appropriate. For example, if felted Nomex bags are chosen for gas stream conditions that are high in temperature and somewhat alkaline (see Table 4-1), pulse-jet cleaning would most likely be used.

The **ratio of filtering time to cleaning time** is the measure of the percent of time the filters are performing. This general, “rule-of-thumb” ratio should be at least 10:1 or greater (McKenna and Furlong 1992). For example, if the bags need shaking for 2 minutes every 15 minutes they are on-line, the baghouse should be enlarged to handle this heavy dust concentration from the process. If bags are cleaned too frequently, their life will be greatly reduced.

Cleaning and filtering stress is very important to minimize bag failures. The amount of flexing and creasing to the fabric must be matched with the cleaning mechanism and the A/C ratio; reverse-air is the gentlest, shaking and pulse-jet place the most vigorous stress on the fabric. For example, it would probably not be advisable to use woven glass bags on a shaker baghouse. These bags would normally not last very long due to the great stress on them during the cleaning cycle. However, fiberglass bags are used on reverse-air baghouses that use shake-and-deflate cleaning. Also, some heavy woven glass bags (16 to 20 oz) are used on pulse-jet units (which also have high cleaning stress).

Bag spacing is very important for good operation and ease of maintenance. Bag spacing affects the velocity at which the flue gas moves through the baghouse compartment. If bags are spaced too close together, the gas velocity would be high because there is very little area between the bags for the gas stream to pass through. Settling of dust particles during bag cleaning would become difficult at high velocities. Therefore, it is preferable to space bags far

enough apart to minimize this potential problem but not so far apart as to increase the size of the baghouse shell and associated costs.

For pulse-jet baghouses, bag spacing is important to prevent bag abrasion. Bag-to-bag abrasion can occur at the bottom of the bags because the bags are attached to the tube sheet only at their tops which allows them to hang freely. Slight bows in the bag support cages or a slight warping in the tube sheet can cause bag-to-bag contact at the bottom of the bags.

Finally, access for bag inspection and replacement is important. For example, in a reverse-air unit, sufficient space between bags should be used so that maintenance personnel can check each bag visually for holes. The bag can either be replaced or a cap can be placed on the tube sheet opening to seal off the bag until it is later changed. The bag layout should allow the bag maintenance technician to reach all the bags from the walkway. One measure of bag accessibility is called bag reach and is the maximum number of rows from the nearest walkway. There is no single value for bag reach, but typical units have a value of 3 or 4.

The **compartment design** should allow for proper cleaning of bags. The design should include an extra compartment to allow for reserve capacity and inspection and maintenance of broken bags. Shaker and reverse-air cleaning baghouses that are used in continuous operation require an extra compartment for cleaning bags while the other compartments are still on-line filtering. Compartmentalized pulse-jet units are frequently being used on municipal solid waste and hazardous waste incinerators for controlling particulate and acid gas emissions.

The design of **baghouse dampers** (also called baghouse valves) is important. Reverse-air baghouses use inlet and outlet dampers for gas filtering and bag cleaning sequences. As described in Lesson 2, during the filtering mode, the compartment's outlet gas damper and inlet dampers are both open. During the cleaning sequence, the outlet damper is closed to block the flow of gas through the compartment. The reverse-air damper is then opened to allow the air for bag cleaning to enter the compartment.

Dampers are occasionally installed in by-pass ducts. By-pass ducts, which allow the gas stream to by-pass the baghouse completely, are a means of preventing significant damage to the bags and/or baghouse. Dampers in by-pass ducts are opened when the pressure drop across the baghouse or the gas temperature becomes too high. However, many state regulatory agencies have outlawed the use of baghouse by-pass ducts and dampers to prevent the release of unabated particulate emissions into the atmosphere.

Space and cost requirements are also considered in the design. Baghouses require a good deal of installation space; initial costs, and operating and maintenance costs can be high. Bag replacement per year can average between 25 and 50% of the original number installed, particularly if the unit is operated continuously and required to meet emission limits less than 0.010 gr/dscf. This can be very expensive if the bags are made of Teflon which are approximately \$100 for a 5-inch, 9-foot long bag, or Gore-tex which are approximately \$140 for a 6-inch, 12-foot long bag.

The **emission regulations in terms of grain-loading and opacity requirements** will ultimately play an important role in the final design decisions. Baghouses usually have a collection efficiency of greater than 99%. Many emission regulations (and permit limits) require that industrial facilities meet opacity limits of less than 10% for six minutes, thus requiring the baghouse to operate continuously at optimum performance.

Typical Air-To-Cloth Ratios

During a permit review for baghouse installations, the reviewer should check the A/C ratio. Typical A/C ratios for shakers, reverse-air, and pulse-jet baghouses are listed in Table 3-1, Lesson 3.

Baghouses should be operated within a reasonable design A/C ratio range. For example, assume a permit application was submitted indicating the use of a reverse-air cleaning baghouse using woven fiberglass bags for reducing particulate emissions from a small foundry furnace. If the information supplied indicated that the baghouse would operate with an A/C ratio of 6 (cm³/sec)/cm² [12 (ft³/min)/ft²] of fabric material, you should question this information. Reverse-air units should be operated with a much lower A/C ratio, typically 1 (cm³/sec)/cm² [2 (ft³/min)/ft²] or lower. The fabric would probably not be able to withstand the stress from such high filtering rates and could cause premature bag deterioration. Too high an A/C ratio results in excessive pressure drops, reduced collection efficiency, blinding, and rapid wear. In this case a better design might include reducing the A/C ratio within the acceptable range by adding more bags. Another alternative would be to use a pulse-jet baghouse with the original design A/C ratio of 6 (cm³/sec)/cm² [12 (ft³/min)/ft²] and use felted bags made of Nomex fibers. However, Nomex is not very resistant to acid attack and should not be used where a high concentration of SO₂ or acids are in the exhaust gas. Either alternative would be more acceptable to the original permit submission.

Typical air-to-cloth ratios for baghouses used in industrial processes are listed in Tables 5-1 and 5-2. Use these values as a guide only. Actual design values may need to be reduced if the dust loading is high or the particle size is small. When compartmental baghouses are used, the design A/C ratio must be based upon having enough filter cloth available for filtering while one or two compartments are off-stream for cleaning.

Table 5-1. Typical A/C ratios [(ft³/min)/ft²] for selected industries¹			
Industry	Fabric filter air-to-cloth ratio		
	Reverse air	Pulse jet	Mechanical shaker
Basic oxygen furnaces	1.5-2	6-8	2.5-3
Brick manufacturing	1.5-2	9-10	2.5-3.2
Castable refractories	1.5-2	8-10	2.5-3
Clay refractories	1.5-2	8-10	2.5-3.2
Coal-fired boilers	1-1.5	3-5	-
Conical incinerators	-	-	-
Cotton ginning	-	-	-
Detergent manufacturing	1.2-1.5	5-6	2-2.5
Electric arc furnaces	1.5-2	6-8	2.5-3
Feed mills	-	10-15	3.5-5
Ferroalloy plants	2	9	2
Glass manufacturing	1.5	-	-
Grey iron foundries	1.5-2	7-8	2.5-3
Iron and steel (sintering)	1.5-2	7-8	2.5-3
Kraft recovery furnaces	-	-	-

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Table 5-1. (continued)
Typical A/C ratios [(ft³/min)/ft²] for selected industries¹

Industry	Fabric filter air-to-cloth ratio		
	Reverse air	Pulse jet	Mechanical shaker
Lime kilns	1.5-2	8-9	2.5-3
Municipal and medical waste incinerators	1-2	2.5-4	-
Petroleum catalytic cracking	-	-	-
Phosphate fertilizer	1.8-2	8-9	3-3.5
Phosphate rock crushing	-	5-10	3-3.5
Polyvinyl chloride production	-	7	-
Portland cement	1.2-1.5	7-10	2-3
Pulp and paper (fluidized bed reactor)	-	-	-
Secondary aluminum smelters	-	6-8	2
Secondary copper smelters	-	6-8	-
Sewage sludge incinerators	-	-	-
Surface coatings spray booth	-	-	-

1. High efficiency: a sufficiently low grain loading to expect a clear stack.
 Source: EPA 1976, revised 1992.

Table 5-2. Typical A/C ratios for fabric filters used for control of particulate emissions from industrial boilers.

Size of boiler (10 ³ lb steam per hour)	Temperature (°F)	Air-to-cloth ratio [(ft ³ /min)/ft ²]	Cleaning mechanism	Fabric material
260 (3 boilers)	400°	4.4:1	On- or off-line pulse-jet or reverse-air	Glass with 10% Teflon coating (24 oz/yd ²)
170 (5 boilers)	500°	4.5:1	Reverse-air with pulse-jet assist	Glass with 10% Teflon coating
140 (2 boilers)	360°	2:1	Reverse-air	No. 0004 Fiberglass with silicone- graphite Teflon finish
250	338°	2.3:1	Shake and deflate	Woven Fiberglass with silicone graphite finish
200 (3 boilers)	300°	3.6:1	Shake and deflate	Woven Fiberglass with silicone- graphite finish
400 (2 boilers)	Stoker, 285° to 300°; pulverized coal, 350°	2.5:1	Reverse-air	Glass with Teflon finish
75	150°	2.8:1	Reverse-air	Fiberglass with Teflon coating
50	350°	3:1	On-line pulse- jet	Glass with Teflon finish
270 (2 boilers)	330°	3.7:1	On-line pulse- jet	Teflon felt (23 oz)
450 (4 boilers)	330°	3.7:1	On-line pulse- jet	Teflon felt (23 oz)
380	NA	2:1	Reverse-air vibrator assist	Glass with 10% Teflon coating
645	NA	2:1	Reverse-air vibrator assist	Glass with 10% Teflon coating
1440 (3 boilers)	360°	3.4:1	Shake and deflate	Woven Fiberglass with silicone- graphite finish

Source: EPA 1979.

Simple Cloth Size Check

Baghouse sizing is done by the manufacturer. This example will show you how to verify the manufacture's measurements by doing a simple cloth size check. Given the process gas exhaust rate and the filtration velocity, you can estimate the amount of cloth required by the baghouse. Once you know the total amount of cloth required and the dimensions of a bag, you can calculate the number of bags in the baghouse.

Problem

Calculate the number of bags required for an 8-compartment pulse-jet baghouse with the following process information and bag dimensions.

Q, process gas exhaust rate 100,000 ft³/min

A/C, gross air-to-cloth ratio 4 (ft³/min)/ft²

Bag dimensions:

bag diameter 6 in.

bag height 12 ft

Solution

1. **Calculate the total gross cloth area.** Use equation 3-6 (in Lesson 3):

$$v_f = \frac{Q}{A_c} \text{ or } A_c = \frac{Q}{v_f}$$

Where: A_c = cloth area, ft²

Q = process exhaust rate, ft³/min

v_f = filtration velocity, ft/min

$$\begin{aligned} A_c &= \frac{100,000 \text{ ft}^3 / \text{min}}{4 \text{ ft} / \text{min}} \\ &= 25,000 \text{ ft}^2 \end{aligned}$$

2. **Determine the amount of fabric required per bag.** Use the formula:

$$A_b = \pi dh$$

Where: A_b = area of bag, ft²

π = 3.14

Given: d = 0.5 ft, bag diameter

h = 12 ft, bag height

$$\begin{aligned} A_b &= 3.14 \times 0.5 \text{ ft} \times 12 \text{ ft} \\ &= 18.84 \text{ ft}^2 \text{ required per bag} \end{aligned}$$

3. **Calculate the number of bags required in the baghouse.**

$$\text{Number of bags} = \frac{A_c}{A_b}$$

From step 1: $A_c = 25,000 \text{ ft}^2$

From step 2: $A_b = 18.84 \text{ ft}^2$

$$\begin{aligned}\text{Number of bags} &= \frac{25,000 \text{ ft}^2}{18.84 \text{ ft}^2} \\ &= 1,326.96 \text{ bags} \\ &\text{or } 1,328 \text{ bags}\end{aligned}$$

So there will be an even number of bags in each of the 8 compartments, round the value 1326.96 up to the next highest multiple of 8 (i.e. 1,328). Thus, there will be 166 bags ($1,328/8$) in each compartment.

4. **Calculate the net air-to-cloth ratio.** As you recall from Lesson 3, the net air-to-cloth ratio is the A/C ratio when one compartment is taken off-line for bag cleaning or maintenance. Use the formula:

$$(A/C)_{\text{net}} = \frac{Q}{A_c \left(\frac{\text{total \# of compartments} - 1}{\text{total \# of compartments}} \right)}$$

Given: $Q = 100,000 \text{ ft}^3/\text{min}$, process exhaust gas rate
The total number of compartments is 8.

From step 1: $A_c = 25,000 \text{ ft}^2$, total cloth area

$$\begin{aligned}(A/C)_{\text{net}} &= \frac{100,000 \text{ ft}^3 / \text{min}}{25,000 \text{ ft}^2 (7/8)} \\ &= 4.57 (\text{ft}^3 / \text{min}) / \text{ft}^2\end{aligned}$$

Or, you can simply divide the gross air-to-cloth ratio by $7/8$.

$$\begin{aligned}(A/C)_{\text{net}} &= \frac{4 (\text{ft}^3 / \text{min}) / \text{ft}^2}{7/8} \\ &= 4.57 (\text{ft}^3 / \text{min}) / \text{ft}^2\end{aligned}$$

5. **Calculate the net, net air-to-cloth ratio** (when two compartments are off-line).

$$(A/C)_{\text{net, net}} = \frac{(A/C)_{\text{gross}}}{\frac{[(\text{total \# of compartments}) - 2]}{\text{total \# of compartments}}}$$

$$\begin{aligned}(A/C)_{\text{net, net}} &= \frac{4 (\text{ft}^3 / \text{min}) / \text{ft}^2}{6/8} \\ &= 5.33 (\text{ft}^3 / \text{min}) / \text{ft}^2\end{aligned}$$

Review Exercise

1. From the baghouses listed below, which would take up less space because of high filter rates?
 - a. Shaker
 - b. Pulse-jet
 - c. Reverse-air
2. True or False? Gas and dust stream properties influence filter choice.
3. An appropriate “rule of thumb” ratio of filtering time to cleaning time should be at least:
 - a. 3:1
 - b. 1.5:1
 - c. 5:1
 - d. 10:1
4. True or False? An air-to-cloth ratio that is too high results in reduced pressure drops.
5. Nomex is not very resistant to:
 - a. HCl
 - b. CO₂
 - c. SO₂
 - d. Lead
 - e. a and c, only
6. Calculate the area of a bag (A_b) given a bag diameter of 15 inches and a bag height of 20 feet.
 - a. 942 ft²
 - b. 70.5 in.²
 - c. 78.5 ft²
 - d. 25 ft²
7. If the cloth area (A_c) is known to be 4,050 ft², how many bags would be used in a baghouse with the bag area (A_b) given above?
 - a. 52 bags
 - b. 519 bags
 - c. 120 bags
 - d. 10 bags
8. A baghouse has 8 compartments and a gross air-to-cloth ratio of 2.0 (ft³/min)/ft². What is the net air-to-cloth ratio?
 - a. 1.75 (ft³/min)/ft²
 - b. 2.29 (ft³/min)/ft²
 - c. 2.66 (ft³/min)/ft²
 - d. 16.0 (ft³/min)/ft²

9. For the baghouse information given in question 8 above, what is the net, net air-to-cloth ratio?
- a. $1.75 \text{ (ft}^3/\text{min)}/\text{ft}^2$
 - b. $2.29 \text{ (ft}^3/\text{min)}/\text{ft}^2$
 - c. $2.67 \text{ (ft}^3/\text{min)}/\text{ft}^2$
 - d. $16.0 \text{ (ft}^3/\text{min)}/\text{ft}^2$

Review Answers

1. **b. Pulse-jet**

Due to their high filter rates, pulse-jet baghouses take up less space than shaker and reverse-air baghouses.

2. **True**

Gas and dust stream properties influence filter choice.

3. **d. 10:1**

An appropriate “rule of thumb” ratio of filtering time to cleaning time should be at least 10:1. If the ratio is much lower, the bags would be cleaned too frequently and may wear out too quickly.

4. **False**

An air-to-cloth ratio that is too high results in *higher* pressure drops.

5. **e. a and c, only**

Nomex is not very resistant to HCl and SO₂ (acid gases).

6. **c. 78.5 ft²**

Solution:

1. Calculate the area of a bag (A_b).

$$A_b = \pi dh$$

Given: $\pi = 3.14$
 $d = 15$ in., diameter of bag
 $h = 20$ ft, height of bag

$$\begin{aligned} A_b &= 3.14 \times 15 \text{ in.} \times \frac{1 \text{ ft}}{12 \text{ in.}} \times 20 \text{ ft} \\ &= 78.5 \text{ ft}^2 \end{aligned}$$

7. **a. 52 bags**

Solution:

1. Calculate the number of bags.

$$\text{Number of bags} = \frac{A_c}{A_b}$$

Given: $A_c = 4,050 \text{ ft}^2$, the total cloth area
 $A_b = 78.5 \text{ ft}^2$, the area of a bag

$$\begin{aligned}\text{Number of bags} &= \frac{4,050 \text{ ft}^2}{78.5 \text{ ft}^2} \\ &= 52 \text{ bags}\end{aligned}$$

8. **b. 2.29 (ft³/min)/ft²**

Solution:

1. Calculate the net air-to-cloth ratio using the following equation:

$$(A/C)_{\text{net}} = \frac{(A/C)_{\text{gross}}}{\frac{[(\text{total \# of compartments}) - 1]}{\text{total \# of compartments}}}$$

Given: $(A/C)_{\text{gross}} = 2.0 \text{ (ft}^3/\text{min)}/\text{ft}^2$
 The total # of compartments is 8.

$$\begin{aligned}(A/C)_{\text{net}} &= \frac{2 \text{ (ft}^3/\text{min)}/\text{ft}^2}{7/8} \\ &= 2.29 \text{ (ft}^3/\text{min)}/\text{ft}^2\end{aligned}$$

9. c. **2.67 (ft³/min)/ft²**

Solution:

1. Calculate the net, net air-to-cloth ratio using the following equation:

$$(A/C)_{\text{net, net}} = \frac{(A/C)_{\text{gross}}}{\frac{[(\text{total \# of compartments}) - 2]}{\text{total \# of compartments}}}$$

Given: $(A/C)_{\text{gross}} = 2.0 \text{ (ft}^3/\text{min)}/\text{ft}^2$

The total # of compartments is 8.

$$\begin{aligned}(A/C)_{\text{net, net}} &= \frac{2 \text{ (ft}^3/\text{min)}/\text{ft}^2}{6/8} \\ &= 2.67 \text{ (ft}^3/\text{min)}/\text{ft}^2\end{aligned}$$

Bibliography

- Fine particle fabric filtration. Proceedings: Symposium on the use of fabric filters for the control of submicron particulates. April 8-10, 1974. Boston, MA. *Journal of the Air Pollution Control Association*. 24(12):1139-1197.
- McKenna, J. D. and D. Furlong. 1992. Fabric filters. In A. J. Buonicore and W. T. Davis (Eds.), *Air Pollution Engineering Manual*. New York: Van Nostrand Reinhold.
- McKenna, J. D. and J. H. Turner. 1989. *Fabric Filter-Baghouses I, Theory, Design, and Selection*. Roanoke, VA: ETS.
- Proceedings: The user and fabric filtration equipment III. October 1-3, 1978. Air Pollution Control Association Specialty Conference. Niagara Falls: NY.
- U.S. Environmental Protection Agency. 1976. Capital and Operating Costs of Selected Air Pollution Control Systems. EPA 450/3-76-014.
- U.S. Environmental Protection Agency. 1979. Particulate Control by Fabric Filtration on Coal-Fired Industrial Boilers. EPA 625/2-79-021.